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TRENCHING MACHINE WORK¹

BY WILLIAM W. BRUSH

In 1909-1910, the City of New York installed between Valley Stream and Amityville, Long Island (a distance of 83,800 feet) a 72-inch lock bar $\frac{1}{8}$ -inch steel pipe as a portion of its Brooklyn conduit system. The contract, which was dated November 6, 1908, was awarded to the T. A. Gillespie Company, and the total estimated cost for all the work, which included culverts, valve chambers, valves, and other appurtenances, was \$1,879,390.

That portion of Long Island traversed by the pipe is an almost level sandy plain, there being only a few feet difference in elevation between the small valleys and the low intervening ridges. The material to be excavated was sand with some gravel and a light sandy top soil. A right of way, in general 200 feet in width, with few cross roads, gave opportunity for the use of any excavating system.

The contractors used practically every known method in excavating the trench, including hand, horse and scraper, clamshell buckets, steam shovels, and the Austin trenching machine. The trenching machine was used for the greater part of the work. It could be and was operated from the shallowest trench section up to a maximum depth of about 10 feet, the limiting depth being determined by the resultant width of trench, it being necessary to have a secure track foundation on each side of the trench on which the machine traveled and by which it was supported. Where the depth of the trench was greater than 10 feet, the contractor removed a portion of the material by other methods and then used the trenching machine.

In a section where the average depth of cut was 8 feet, and the work was performed during a period of one month, data are available on which an accurate determination of the cost of excavation by this method can be worked out.

Two machines were regularly employed, working in tandem, one machine removing approximately half the material and the other

¹ Read at the Richmond Convention, May 10, 1917.

machine completing the trench. This method was considered to give maximum rate of progress. The contractors were desirous of completing the work as rapidly as possible and the methods adopted were based first on progress and second on unit cost.

The two machines used were not owned by the T. A. Gillespie Company but were rented from the F. C. Austin Drainage Excavator Company at a yearly rental of \$8500 and \$9300 respectively. This rental was based on the total yardage excavated by either machine being 100,000 cubic yards or less, all over and above 100,000 cubic yards being paid for at the rate of \$0.055 per cubic yard. The machines were worked in tandem for the greater part of the work and in many cases for the twenty-four hours in each day.

To determine the cost per cubic yard for excavating the trench by use of the trenching machine, a length of trench was taken extending from Station 969 + 52 to Station 1092 + 92 or a total of 12,140 feet. The machines were worked in this section three shifts per 24 hours for one month from May 15 to June 16, 1909. An accurate force account was kept by the Department for this period.

The total cost of excavating per cubic yard was subdivided under the following: (1) Rental of machines; (2) repairs and coal for machines; (3) labor force. The total amount of excavation made by the two machines was approximately 400,000 cubic yards or 200,000 cubic yards for each machine. The cost for rental per cubic yard would therefore be for

Machine 1:	the first 100,000 cubic yards	\$0.085
	the second 100,000 cubic yards	0.055
Machine 2:	first 100,000 cubic yards	0.093
	the second 100,000 cubic yards	0.055

The average for both machines would be \$0.072 per cubic yard.

The trenching machine excavated the trench with side slopes of 1 on 1 and the bottom of the trench was rounded to conform with the curve of the pipe. The average depth of the trench for the 12,140 feet excavated was approximately 8 feet. This gave a total of 48,560 cubic yards or 4 cubic yards per linear foot of trench. The repairs on the two machines for the first six months, including the cost of setting up, amounted to \$6,000 and the cost of coal for the same period was \$2000. The cost for repairs, coal, etc., for one month would be \$1334 or \$0.0275 per cubic yard.

The force included: (a) The men who operated the machines;

(b) the gang laying and shifting the track and moving machines; (c) the gang who trimmed the trench to grade after the machine had passed.

This force was as follows:

General foreman, two months at \$125.....	\$250.00
Foreman, 143.5 days at \$2.50.....	358.75
Laborers, 2368 days at 1.40.....	3,315.20
Teams, 266 days at.... 5.00.....	1,330.00
Boys, 45 days at..... 0.75	33.75
Engineman, 176 days at 4.00	704.00
Foreman, 171 days at. 3.00	513.00
Skilled laborers 15 days at..... 2.00	30.00
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	\$6,534.70

This cost of labor shows a cost per lineal foot of trench of \$0.5382 and a cost per cubic yard of excavation of \$0.1345.

The total cost for excavation per cubic yard would be:

Rental of machine.....	\$0.072
Repairs and coal for machine.....	0.0275
Labor.....	0.1345
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	\$0.2340

This cost per cubic yard is equivalent to \$0.936 per lineal foot of trench.

The following summary of the cost per lineal foot for laying the pipe will enable a comparison to be made between the excavation cost and that of other factors in the work:

Clearing and grubbing.....	\$0.037
Excavating.....	0.928
Unloading and distributing.....	0.1911
Laying.....	0.2166
Digging bell holes.....	0.084
Riveting.....	0.345
Calking.....	0.288
Testing.....	0.24
Backfilling.....	1.061
Cleaning up, etc.....	0.0993
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	\$3.49

It is interesting to note that on this job, the backfilling cost 15 per cent more than the excavation. The usual experience warrants an estimate to backfill at a materially lower cost than the excavation.

The author is indebted to Charles J. Clark, assistant engineer in the Department of Water Supply, Gas and Electricity, for the data presented herein.

DISCUSSION

THEODORE A. LEISEN: Trench machines, like automatic stokers, may not have been at one time popular because they could not vote, but conditions have arisen recently that give an entirely different aspect to the question. Because of the difficulty of procuring labor, it is absolutely necessary to use devices that will reduce the amount of labor required. During the latter part of last year the Detroit Water Department started purchasing trench machines, and up to the present time it has bought five, two small, one of medium size, and two large enough to excavate trenches 6 feet wide for laying 48-inch mains. Two of these are of the rotary type, and the other three are of the ladder type, made particularly for water pipe work digging to a depth of 10 feet maximum.

There are many places within the built-up sections of a city where a machine cannot be used advantageously. If the gas mains and electric conduits were installed prior to the time that the water main is laid in that section, the cross-connecting services would make an excavating machine out of the question, because unless it can be run continuously there is no particular advantage to be gained in its use. Another thing which sometimes interferes with its use in suburban sections, particularly if the mains are to be laid back of the curb, is the planting of trees in too close proximity to the curb, which renders it impossible to use a machine; but in general, on suburban work where a main is being laid in new territory, a machine can be used to very great advantage. The records are submitted for what they are worth, covering three months, October, November and December, 1916. Any records for January, February or March, 1917, would be of little or no value, because the winter work, particularly last winter, has been abnormal owing to the very deep frost in the ground, and even where the trench machine was used it was necessary to burn out the frost before the machine would work to any great advantage.

Comparisons for the last three months of 1916 show the follow-

ing: For 6-inch pipe with hand labor, 42 cents, and with machine work, 30 cents, a decrease of 12 cents per foot in favor of the machine. On 8-inch pipe, 45 cents with hand labor and 31 cents with a machine, a decrease of 14 cents in favor of the trench machine. On 12-inch pipe the cost by hand was 67 cents and by machine 40 cents, a saving of 27 cents in favor of the trench machine. On 16-inch pipe the cost by hand was \$1.43 and by machine \$1.13, showing a saving of 40 cents per foot in favor of the trench machine. As the size of the pipe increases the saving will become greater and greater, other conditions being equal. The trenches are $5\frac{1}{2}$ to 6 feet deep for pipe up to and including 12 inches in diameter.

Under the method of laying pipe in Detroit there is one fact that militates against the most advantageous use of the trench machine, namely, every pipe line is tested before it is covered. A section 300 to 1000 feet long is laid, according to conditions, and then it is tested under a pressure of 100 pounds before any backfilling is done. If the excavation is in good stiff clay or reasonably good earth and the banks will stand up, it does not make so much difference; but if it is sandy soil or wet ground where pavements are contiguous, it is much more difficult to excavate for any great distance ahead of the pipe work; and consequently the machine must stand idle until the test is completed. The prices given include a fixed charge on the machine, which covers all the labor on the machine and a certain charge for its depreciation, so that the hand labor and machine work are placed on a perfectly equal basis for comparison.

In addition to the trench diggers the Detroit department is using a number of gasoline operated backfillers of the simpler type, two of them being boom machines, the boom being about 30 feet long, each supposed to work with two men but usually requiring three men to operate it. The saving in machine backfilling is very material as compared with hand work. Where the trenching has been done before the streets were paved the backfilling is heaped up over the ditch and watched until it comes down to a reasonably level surface. Where the pavement is to be put down the backfilling is rammed by hand. A machine-rammer has been tried with only indifferent success.

Trench machines are used generally in sections over 400 feet long, and preferably on the longest extensions that are being made at any particular time and place. It does not pay to put the machine in a trench 200 or 300 feet in length unless it happens to be adjacent to some larger work.

The machines are all self-propelling, and will move at the rate of about three to five miles a day, according to conditions. The smaller machines can be relied upon to excavate up to 1000 feet per day of ten hours, provided there are no obstructions to interfere with their progress. The larger machines will not dig so rapidly. The question of just what they will average in actual work from month to month is rather difficult to put down in figures, because there are so many conditions which may come up to interfere in one way or another with the continuous progress of the machine. From 300 to 1000 feet is what a machine can do. Four of these machines are gasoline-operated; one of the large machines is steam operated.

The machine proper is ahead of the cut, so that its weight has no effect whatever on the caving in of the sides of the trench except insofar as this weight in passing in advance of the excavation may disturb the surface of the earth. In excavating in sandy soil, to prevent to a certain extent the tendency to cave in, a single plank bracing is placed on each side of the trench from 18 to 24 inches below the surface and held in place by extension braces. In some instances the sides will slough in in spite of this bracing, but not sufficiently to interfere materially with the laying of the pipe, and to no greater extent than would be the case in hand-excavated trenches.

C. W. WILES: At Marion, Ohio, a trench machine was used last year in laying several miles of 6 and 8-inch pipe $4\frac{1}{2}$ or 5 feet deep. A contract was made simply for the excavation of the trench ready for the pipe; the price paid was 10 cents per lineal foot. The speaker has just closed a contract for a trench in which to lay some 6-inch pipe $4\frac{1}{2}$ feet deep, at $6\frac{1}{2}$ cents per lineal foot, which is very cheap indeed. The trench will be 20 inches wide on the top and slope down. It is doubtful whether the work could be done at 20 cents a foot by hand labor.

R. B. HOWELL: During the past three years a ditching machine has been used in laying some 30 miles of pipe in Omaha. The actual cost of labor, maintenance and operation, not including depreciation, has been between 3 and 4 cents per running foot of trench. However, the department has charged the work with a total of 6 cents per running foot, the additional amount being added for depreciation. On this basis, the machine has been fully paid for and it is still in fair working condition. It digs a trench about $5\frac{1}{2}$ to 6 feet

in depth, and the water department increased its cutting width so that it has cut a trench for some 4 miles of 24-inch pipe. The back-filling was done by scrapers, and by hand where necessary. There is no question as to the advantages of the use of such a machine, except on short piece work. It is necessary, after the machine has been taken out upon the streets and put into service, to keep a watchman on it at night. Because of this expense the water department waits until a considerable amount of pipe laying work has accumulated, and then works the machine continuously. It has also been rented occasionally to the Telephone Company for the installation of conduits, that company using the water department's help in its operation.

E. E. DAVIS: The trench machine has been found very satisfactory at Richmond. The soil is either red clay, sand or gravel. The pipe is laid at an average depth of 4 or 5 feet. A machine has made as much as 1100 feet in one day, when excavating for 8-inch pipe.

LEONARD METCALF: The speaker remembers one case in Louisville on sewerage work where the use of the machine in a sandy and gravelly soil did not pay, because the banks caved so badly. On the other hand, he has seen trenches in the West where it was used successfully by placing poling boards or stay-bracing immediately behind the machine. Some caving did result, but on the whole there was a saving in cost by the use of the machine.

Of course the material dealt with determines the saving. If there is no cohesiveness in the material, obviously the machine cannot be used to advantage, because under such circumstances the trench will cave before such bracing as may be required can be placed.

A much more extensive use of the machine has been made in localities west of the Mississippi rather than east of it. The machines are well fitted to the prairie soils of the West. In Los Angeles, William Mulholland is using the machine very successfully with his outlying pipe lines, not in the heart of the city or where there are many obstructions. In the San Francisco region the speaker found the machine was used very little, though in a recent trip he found that in Sacramento several of the machines were being used successfully. In Denver the machines were in use for sewer work in some trenches upwards of 12 feet deep, 4 feet and a little over in width;

the additional width being obtained there, as in Los Angeles, by breaking down the banks with a bar as the machine went along and letting the machine excavate the material which was broken down.

Of course there is a great variety of conditions, and these affect the extent to which the machine can be used. The speaker remembers one contract in Denver in which the contractor meant to use the machine wholly. Some pipe was to be laid in an alley, where no obstructions were anticipated. A well-known engineer of that region kept a careful cost account for the contractor. It showed that about one-half of the work had finally to be done by hand, but that the use of the machine was nevertheless advantageous. Moreover the machine was used in many places where obstructions had to be skipped. Of course had there been many of those, the saving in cost would have been seriously affected.

The speaker is of the opinion that Mr. Leisen's statement upon the limitations of machine use, on short sections of trench, represents general experience. The speaker was very much interested in hearing a case in central New York a few weeks ago, in which a machine had been used in the down-town district successfully, but that success with it probably was due to the particular skill of the man who ran the machine. He was a careful operator. On the other hand, in Denver, the gas department suffered much from the carelessness with which some of the sewer work was conducted, which led to the necessity of expensive repairs to the gas services. In the central New York case cited the superintendent made reference to the fact that there had been a great demand for the machine outside of the Water Department, and a great deal of trenching for drains and other purposes had been done by the machine which had enabled the charging off of the cost of the machine.

The Indianapolis Water Company's pipe laying records for the last five years were analyzed with great care by the speaker recently. In that period of time it was found that the trench machine had been used to do about one-quarter of the work. Had it been advantageous to use it more, it would have been employed. The general experience showed that it was not advantageous to get the machine out, particularly in a distant part of the city, unless the extension approximated 1000 feet. In some cases it was perhaps nearer 500 feet; but for an extension of 300 feet it had not proved advantageous. The saving in cost per cubic yard amounted to about one-quarter, if the speaker remembers the figures, the ratios being about as 30 to 41.6

cents on the excavation, backfilling, and complete earthwork, without any allowance for depreciation and interest charges upon the machine. Making an allowance in accord with experience there with the machine, it brought the cost up to almost exactly the cost of the hand-work which had been done, the relative costs then being 38.3 cents and 41.6 cents per cubic yard. During the period of time covered by this investigation the Department would, in some cases where the machine was used, have experienced great difficulty in getting the work done by hand-labor, because of scarcity of labor. From a public point of view in many cases the machine has a distinct advantage in reducing the time limit involved; so that it seems probable that even though there might not be great saving in cost in some cases, the trench machine will come to be more generally used in the East than heretofore. Its use is growing.

M. N. BAKER: It seems obvious that under existing and near future conditions the trench machine and all other labor-saving machines, not only in water-works but in all municipal work, will be far more extensively used than in the past. Labor and other conditions seem to make this almost a matter of compulsion, and as a matter of patriotism we certainly shall have to use machines to save men whenever that can be done. It seems to the speaker from information he has collected in the past few months, that it is possible to use trench and other machines in places where their use has very frequently been thought impossible or undesirable. While one man may report that it is entirely out of the question to use the trench machine under certain conditions, other men in other cities say that they have been used under equally difficult conditions with success.

A. PRESCOTT FOLWELL: A trench machine was working in Baltimore a few years ago in loose caving soil. An inclined platform, making an angle of about 20 degrees with the horizontal, was supported just ahead of the completed trench in which the pipe was laid, and provided with side-boards. A drag scraper filled with soil was dragged up this platform, and on reaching the end of it, where the trench was ready for backfilling, it was automatically dumped into the trench. With this contrivance there was of course no difficulty on account of the caving of the sides of the bank and no shoring was required. The depth of the trench was regulated by hand by the operator who guided the scraper.

A Thew shovel has been used for digging a trench in which the bank stood up very well, and there was no caving to amount to anything. The trench was being dug for either a 24 or 30-inch pipe and 12 feet of trench was excavated quite close to the desired grade by means of the shovel. Each shovelful was deposited as backfilling in the trench behind by simply revolving the shovel and running the bucket arm out its full length. When 12 feet of trench had been so excavated, and had been trimmed sufficiently close to grade by hand by a couple of men with shovels, the iron pipe was laid by the shovel arm itself, the pipe being slung from the arm by ropes. The engineer, by moving the arm up and down, and backward and forward, could enter the pipe into the bell and adjust it to the exact position desired. The joint was immediately poured and calked expeditiously by the use of a pneumatic calker, so that in a few minutes it was possible for the shovel, which in the meantime had gone on digging an additional 12 feet of trench, to backfill over the joint and the pipe just laid.

I. M. HIGBEE: The White Deer Mountain Water Company, in the spring of 1916, decided to construct an auxiliary water pipe line for an additional supply of water. The pipe line is about 8 miles long. To dig this trench by hand, in the time the work had to be done, was out of the question. It was not a matter of wages, but there were no men to be had in numbers large enough to do the work. The company accordingly bought a trenching machine of the rotary type.

The country passed through was all farm land, with rock formation at different points that had to be blasted and dug by hand. At these points, the ditcher traveled over and ahead of the rock and then began to dig again. These jumps varied from 100 to 500 feet. The digger was on the trench 130 days, and was idle about 10 days out of the 130, owing to repairs that had to be made to the machine and for rainy days. The average width of trench was 24 inches and its average depth 42 inches. The digging done by the ditcher amounted to about 8000 cubic yards and it cost \$2500 to dig this with the ditcher.

The above amount or cost of digging trench with the ditcher covers only the operating expenses during the 120 days worked on this construction and consisted of the following items:

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Foreman, water boy and office hire.....	\$500
One engineer, 120 days at \$5.00.....	600
One helper, 120 days at \$2.50.....	300
Gasoline and oil.....	400
Laborers.....	250
Repairs to machine on the work.....	200
Incidentals, etc.....	250
	<hr/>
	\$2,500

The above is only for the digging; the laying, digging bell holes, breaking down, and trimming the bank were kept separate. The cost of the machine was \$3400 and the depreciation should be at least \$750. No allowance was made for interest charges on the investment.

The machine there works most advantageously in any fair to good loam. There was one stretch of trench where it made a run of 3 feet every minute for every working hour. It made a trench 1500 feet long by 24 inches wide by 42 inches deep, with only the engineer and helper, 15 gallons of gasoline and 4 quarts of oil. This was the best run. The machine cannot be operated in rock at all and where the ground has very large round stones it does not do well, but will operate at a slower rate of speed.